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An Analysis of Integrated Product Design and Development Approach for Environmentally Conscious Manufacturing

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Abstract—*Manufacturing companies continue to consider factors such as quality, reliability and cost as success factors for their businesses. However, to achieve an environmentally sustainable production, the principles and methods for the environment friendly design of products need to be integrated into design and managerial practices. Environment conscious manufacturing (ECM) is an emerging discipline that is concerned with developing methods for manufacturing new products from conceptual design to final delivery, and ultimately to end-of-life disposal, that satisfy environmental standards and requirements. Although ECM advocates for the inculcation of environmental requirements and standards in the design and development of a product or process but lacks a comprehensive and exhaustive model for such an integration of environmental and conventional criteria while designing a product or process. This paper presents an analysis of an integrated product design and development approach for ECM based on the understanding of product's life cycle phases.*

Keywords*: Environmentally Conscious Manufacturing; ECM; Integrated Product Design and Development; Product Life Cycle; Design for Environment; DFE; Sustainable Manufacturing.*

1. INTRODUCTION

The issue of environment and global warming is a real challenging threat to the very survival of human kind for which human beings are themselves responsible. The environment is facing the wrath of unplanned Industrialization and rapid development of technologies that are unfriendly to environment. However, of late, there is a never before awareness of this issue among all the major stake holders, viz. government, industry and customers. This has led to the development of more stringent environmental regulations of the government forcing the industry to produce and dispose of the products after the end of their useful life in an environment friendly manner. These environmental regulations also require that the products be safe to the environment during use by the customers. This has given birth to a new discipline called Environment Conscious Manufacturing (ECM) which puts thrust on Product Life Cycle Monitoring [1].

ECM has a variety of definitions:

(a) Environmentally conscious manufacturing (ECM) is concerned with developing methods for manufacturing new products from conceptual design to final delivery and ultimately to the end-of-life (EOL) disposal such that the environmental standards and requirements are satisfied.

(b) Environmentally conscious manufacturing (ECM) is a new way of thinking about manufacturing which focuses on the most efficient and productive use of raw materials and natural resources, and minimizes the adverse impacts on workers and the natural environment. In its most advanced form, a product's entire life cycle is considered, from design, raw material and natural resource use to end use and disposal.

(c) Environment Conscious Manufacturing (ECM) is defined as a set of tools and techniques required for the manufacture of new products as per environmental standards and regulations. It involves developing manufacturing methods responsible for the whole life cycle of the product i.e. from the conceptual design to production to final delivery and finally to end-of-life disposal or recycling or re-manufacture.

It could be concluded from these definitions:

(i) ECM involves both Environmentally Conscious Product Design and Environmentally Conscious Process Design.

(ii) the main objective of ECM is to obtain a product whose manufacture, use, and disposal have the least environmental impact, and to achieve this end ECM has product's life cycle approach.

2. PRODUCT LIFE CYCLE

The various phases or stages of a product's life cycle include Pre-production; Production; Distribution; Use; and End of Useful Life. All these five major phases of a product's physical life cycle calls for specific and multi-pronged strategies for tackling the issue of environmental deterioration and damage.

Pre-production phase involves the preparation and procurement of raw-materials and components required for the production processes and end product.

Production phase builds upon the pre-production phase and involves the transformation of materials, production of components, product assembly and finishing.

After the successful completion of the Production, the Distribution phase begins that involves the packaging and transportation of the end-product.

As soon as the product is shipped and received by the customer, Use of the product begins till the end of its useful life and during its useful life there may be requirement of servicing and spare parts.

At the end of useful life, the various choices may be recycle, reuse, disassembly, remanufacture or simply disposal as waste.

All these phases interact with the ecosphere (environment) with the input flows of materials and energy in each phase from ecosphere and output flows of emission and waste from each phase to ecosphere in the overall production process of end product as shown in Fig. 1.

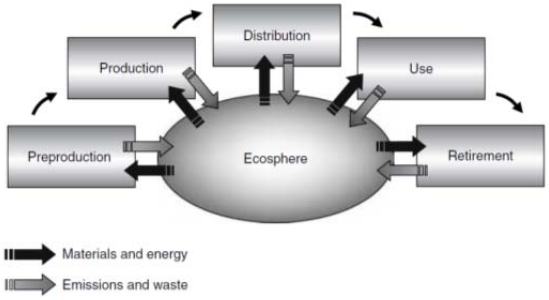

Fig. 1: Interaction of each phase of product's life cycle with the environment [4]

3. DESIGN FOR ENVIRONMENT (DFE)

DFE emphasise that the products be designed and developed for environmental protection in relation to all the phases of a product's life cycle i.e. a systemic approach "from the cradle to the grave" as shown in Fig. 2. DFE involves the recognition and reduction (elimination, if possible) approach to the environmental impacts implicated in the life cycle of a product. It strives for environmental protection both from products and processes involved. DFE adopts a proactive approach in the product design stage by evaluating and systematic reduction or elimination of the potential environmental impacts of a product or process.

Fig. 2: Scope of DFE [4]

Some of the general guidelines and suggestions of DFE [2] to be considered in all the phases of a product's life cycle for an eco-efficient product and process are:

- Making use of recycled and recyclable materials and avoiding toxic or polluting materials**;**
- A modular design approach by using replaceable and recyclable components for a better reliability, maintainability, disassembly, reuse, remanufacturing, waste reduction and an extended product's useful life**;**
- A sharp focus on emission and waste reduction in production processes**;**
- Use of energy efficient components and processes**;**
- A balanced approach to the economic costs and environmental performance of the products and processes**;**
- Products and processes shall operate under the legal environmental constraints and regulations**;** anticipate the future environmental constraints and regulations.

4. ENVIRONMENTAL STRATEGIES AND PRODUCT'S LIFE CYCLE PHASES

In order to implement DFE and ECM, it is required to develop and implement environmental strategies for each phase of a Product's Life Cycle. The aim of these strategies shall be to minimize the quantum of materials and energy used; a closed loop of resource flows through recycle and reuse; minimizations of emissions and waste; and an extended product's useful life [3].

Some of the environmental strategies for Preproduction phase may be to reduce the use of energy and raw materials while making use of those raw materials that are abundantly available, less use of toxic materials, reduction in emissions

and waste. The environmental strategies for Production phase may be to reduce emissions and waste by selecting those processes that have low environmental impact, processes that have high energy and technological efficiency to reduce emissions and waste, making use of recycled and recyclable materials while avoiding toxic materials.

The environmental strategies for Distribution phase may be a selection of energy efficient and less polluting mode of transportation that requires less and reusable packaging, eco-friendly packaging material, careful handling of toxic and hazardous materials. For the Use phase, the strategies may be that the product be operated under optimum and intended conditions, less energy consumption and emissions during use, proper scheduling of maintenance and repair. At the end of useful life, the product shall be such that it facilitates recycle, disassembly, re-use and upon disposal shall have low environmental impact. These strategies may be categorized as Resource-Reduction Strategies, Useful-Life Extension Strategies, and End-of-Life Strategies. Fig. 3 depicts these strategies in relation and relevance to the product's life cycle phases.

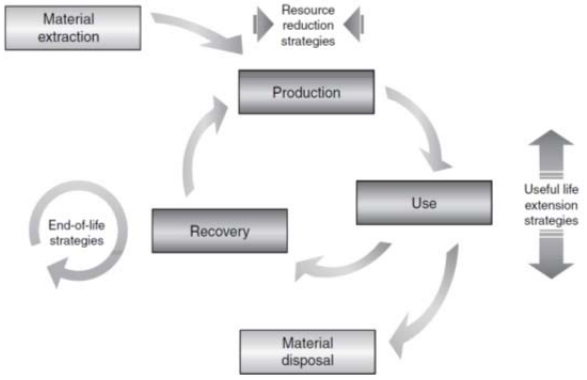

Fig. 3: Environmental strategies for each phase of product's life cycle [4]

Resource-reduction strategies aim at the reduction of the use of materials and energy required for the production of a product. These resource reduction strategies are more effective during product design and production process planning.

The Useful-life Extension strategies focus on increasing the useful life of a product through its maintenance, repair, up-gradation and adaptation. These useful-life extension strategies provide enhanced value to the various resources used for the manufacture of a product.

The objective of the End-of-life strategies is to further harness the value of the various resources used for the manufacture of a product after the useful-life extension strategies fail to deliver. The end-of-life strategies include recycle, reuse and eco-friendly disposal. The overall thrust of all these strategies is to reduce the depletion of resources, pollution and environmental disturbances.

5. DFE AND DFX

DFE is more a design philosophy and lacks true and proper operational design tools whereas DFX is one such approach that has some system tools that can be used for DFE.

DFX is a set of tools and techniques used for designing a product for one or more properties or characteristics required of a product. In DFX, X stands for any property of the product that characterizes it in relation to one or more phases of its life cycle. DFX may be used for inculcating the properties or requisites of a product like functionality, performance, manufacturability, quality, reliability, serviceability, safety, user friendliness, and environmental friendliness and reducing associated costs.

DFX aids in decision making, conducting different types of analysis, to develop appropriate metrics for quantifying the various design alternatives. Some of the most appropriate tools of the DFX system relevant to DFE are Design for Disassembly (DFD), Design for Serviceability (DFS), and Design for Product Retirement or Recovery (DFPR). These DFX tools support the DFE strategies of Resource-Reduction, Useful-Life Extension, and End-of-Life.

Although, the DFX tools that are in tune with the environmental strategies shall command the overall design process of the products for inculcating environmental efficiency into the products but for obtaining a successful design, the results and analysis of the other tools of DFX system such as Design For Manufacturability, Design for Assembly, Design for Variety, Design for Robustness, Design for Quality, and Design for Reliability, needs to be integrated into the design process as a balance is required to be achieved for varying and potentially conflicting requirements of a product such as performance, economic, and environmental.

6. AN INTEGRATED APPROACH TO PRODUCT DESIGN AND DEVELOPMENT FOR ECM

Manufacturing companies continue to consider factors such as quality, reliability and cost as success factors for their businesses. However, to achieve an environmentally sustainable production, the principles and methods for the environment friendly design of products need to be integrated into design and managerial practices as shown in Fig. 4. The manufacturing concerns fail to develop an environment friendly design for their products primarily due to the poor understanding of the environmental requirements and environmental impacts of products, and a cost oriented approach to each and every business activity [4,6,7].

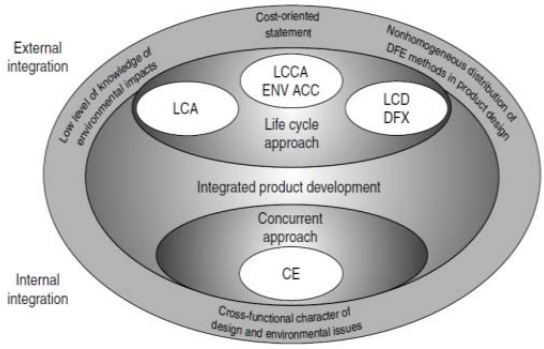

Fig. 4: Integrated Product Development for ECM [4]

The environmental requirements and impacts of a product are to be considered and evaluated for each phase of a Product's Life Cycle. This situation can be handled by adopting the techniques used in Life Cycle Assessment (LCA). LCA is a well-known method of analysis that enables the quantification of the environmental impacts of a process. LCA helps in the identification, quantification, and impact of the resources used as well as the quantification of emissions and waste generated on the use of these resources. A simplified version of LCA known as 'streamlined LCA' could be adopted for preliminary environmental analysis during product development process.

As businesses generally do not appreciate the potential value of an eco-compatible design and consider the environment as a restriction and source of trouble for their business activities, there is a requirement of an accurate economic analysis and environmental value of a product. To facilitate this requirement, life cycle oriented techniques like Life Cycle Cost Analysis (LCCA) and Environmental Accounting may provide a solution.

An environmentally conscious product design and development needs a focussed approach on environmental aspects of the product, which is not just limited to cost, quality, and reliability analysis. This environmentally oriented approach has to be holistic and also directed towards each phase of the product's life cycle. This approach may be taken care of by using tools and techniques like Life Cycle Design (LCD) or Life Cycle Engineering. LCD helps in the seamless integration of environmental requirements and standards in the overall process of product design and development.

Another major impeding factor in the implementation of environmentally oriented design and development in company practice is the cross-functional character of both design practice and environmental aspects. This cross functional character of both design practice and environmental aspects require inputs for the design and development of the products from several specialized teams in a coordinated fashion. To overcome this impeding factor, the technique of Concurrent Engineering (CE) may be implemented.

All these tools and techniques if used in isolation may not be able to produce desired results and thus required to be systematically integrated for an environmentally conscious product design and development process. This integrated product development needs integration at two levels i.e. Internal Integration and External Integration. The external integration is concerned about the integration of product design and development process with the factors external to the design team such as customer, market and environmental requirements of a product. This external integration may be obtained by adopting the life cycle approach and its tools like LCA, LCCA, LCD, DFE, DFX and Environmental Accounting. The internal integration is about the development of synergy among the cross-functional design and development teams for inculcating use of environmental standards and practices in the traditional design and development teams. This internal integration may be achieved by using a simultaneous and concurrent approach to design and development process by exploiting Concurrent Engineering (CE).

This Integrated product design and development through internal and external integration and a life cycle approach is better equipped to design, develop, and deliver a product that fits to its natural environment as much as it fits the business environment.

7. DISCUSSION

The manufacturing concerns fail to develop an environment friendly design and development for their products primarily due to the poor understanding of the environmental requirements and environmental impacts of products, and a cost oriented approach to each and every business activity.

In order to design and develop a green product or process, it is required to develop a better understanding and knowledge of various operational measures and techniques of assessing and improving the environmental performance of a product or process. It is required to develop interface, incorporate and integrate these various environment friendly techniques, strategies and operational measures in the overall process of product design and development to achieve the goals of ECM.

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